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CP Violation in $\Lambda_b \to \Lambda\ell^+\ell^-$ Decay in the Four–Generation Standard Model

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We present the first study of CP asymmetry in $\Lambda_b \to \Lambda\ell^+\ell^-$ decay when a new weak phase comes through the extension of three-generation standard model to the four-generation standard model. Taking $|V^*_{t's}V_{t'b}| = 0.01, 0.02, 0.03$ with phase $\{60^\circ - 120^\circ\}$, which is consistent with the $b \to s\ell^+\ell^-$ rate and the Bs mixing parameter Δm_{Bs}, we find out that CP asymmetry is quite sensitive to the existence of fourth generation. It can serve as a good tool to search for new physics effects, in particular, to search for the fourth generation quarks (t', b') via their indirect manifestations in loop diagrams.

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Although the standard model(SM) of particles explains most experimental results, there are many theoretical shortcomings of the SM and some experimental puzzles which impose extension of the SM in many different ways. Experimental results show discrepancy at the 2–3σ level from the SM predictions such as (a) measurement of direct CP-asymmetry of $B \to K\pi$ decays[1] and (b) the nonvanished CP phase measured in $b \to s$ transition by CDF[2] and DØ,[3] which can not explain by 3×3 CKM matrix. A consequential extension of the three-generation standard model (SM3) to the four-generation standard model (SM4) has better solutions to some of the theoretical and experimental problems. Such extension can include extra weak phases in the quark mixing matrix which can introduce better solutions to the baryon anti-baryon asymmetry of the universe. SM4 can also explain the direct CP-asymmetry of $B \to K\pi$ decays.[4] After analyzing the LEP II results, some of the exports insist that this results exclude the existence of extra generations of the fermion. Some other experts interpret the LEP II results as constraints on the fourth fermion mass which has to be greater than the half of the Z boson mass. Kribs *et al.* pointed out that the existence of fourth fermion cannot contradict the electro-weak precision data.[5]

In this study, we investigate the CP-asymmetry in $\Lambda_b \to \Lambda\ell^+\ell^-$ decay in the SM4. This decay in the quark level is loop induced flavor changing neutral currents (FCNC) of $b \to s\ell^+\ell^-$ transition. The fourth quark (t') such as u, c, t quarks contributes to the $b \to s(d)$ transition at loop level. The CP-asymmetry in the content of the SM is almost zero in the $b \to s\ell^+\ell^-$ transition since the weak phase is almost zero. A new weak phase clearly can affect CPA, which is attempted to examine. The new physical effects can be easily seen in the study of branching ratio,[6] but this physical observable suffers from hadronic uncertainties. The study of ratio of physical observables such as CPA and polarization asymmetries, on the other hand, suffers less from the same uncertainties because those uncertain parameters partially cancel out.

In the mesonic decays, the helicity structure of the effective hamiltonian is obviously absent, on the other hand, the baryonic decays could maintain such structure for the $b \to s$.[7] From this point of view, the study of the baryonic decay is especially important. The Λ_b factorization from $b\bar{b}$ pairs is about 10%.[7] The expected $b\bar{b}$ pairs per year in LHC are $\sim 10^{12}$. As a result, the expected number of Λ_b's are $\sim 10^{11}$. This is quite enough to measure many physical observables.

In the SM4 the full operator sets remain the same as the SM3 for $b \to s\ell^+\ell^-$ transition. The modifications come through the Wilson coefficients resulting from t' contributions in the loop level where the fourth generation up type quark t' is introduced in the same way as u, c, t quarks are employed in the SM. The matrix element of the $\Lambda_b \to \Lambda\ell^+\ell^-$ decay at quark level is described by $b \to s\ell^+\ell^-$ transition for which the effective Hamiltonian can be written as

$$\begin{aligned}\mathcal{H}_{\text{eff}} = \frac{G\alpha}{2\sqrt{2}\pi} V_{tb}V^*_{ts}\Big[& C_9^{\text{tot}}\bar{s}\gamma_\mu(1-\gamma_5)b\bar{\ell}\gamma_\mu\ell \\ & + C_{10}^{\text{tot}}\bar{s}\gamma_\mu(1-\gamma_5)b\bar{\ell}\gamma_\mu\gamma_5\ell \\ & - 2C_7^{\text{tot}}\frac{m_b}{q^2}\bar{s}\sigma_{\mu\nu}q^\nu(1+\gamma_5)b\bar{\ell}\gamma_\mu\ell\Big], \end{aligned} \quad (1)$$

where $q^2 = (p_1 + p_2)^2$, p_1 and p_2 are the momenta of the final leptons. The effective Wilson coefficients (C_i^{tot}'s where $i = 7, 9, 10$) contain two parts. The SM3 parts of the Wilson coefficients in the $\mu = m_b$ scale in the SM3 were given in Refs. [8–10]. The virtual exchange of the fourth generation up type quark t' responsible for the additional part. The above-

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